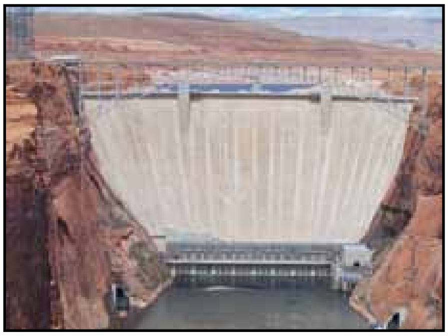
TPG

Volume 51, Number 2 APR/MAY/JUN 2014

INSIDE THIS ISSUE


7


7


45

FEATURES

Cover Photo: Flume Trail in the Granite Dells of Prescott. Photo provided by Prescott Office of Tourism.

A Rapid, Inexpensive and Portable Field and Laboratory Method to Accurately Determine the Specific Gravity of Rocks and Minerals

Dr. Uwe Richard Kackstaetter, MEM-2437,
Metropolitan State University of Denver,
Dep. of Earth & Atmospheric Sciences

Abstract

Advances in load cell weighing scale technology now enable rapid specific gravity (SG) measurements of varied specimens using porTable systems. This investigation demonstrates that the use of small consumer scales, coupled with a hydrostatic method of direct buoyancy displacement measurement for volume, yields a resolution high enough to make these inexpensive balances applicable for serious geologic field and laboratory work. Precision in SG determination of over 95% and accuracies within the 99th percentile established during this study rival sensitive precision analytical laboratory balances, provided that the scales have a minimum resolution of 0.01g. The ease of use, accuracy and portability of this system allows for rapid, quantitative, systematic density determination of geologic materials.

Key-Words: specific gravity, density, minerals, rocks, field method, hydrostatic measurement, load cell balance, electromagnetic balance, precision, accuracy

Introduction

Hydrostatic measurement of specific gravity (SG) in rocks and minerals is not new. One of the earliest precision instruments for measuring the density of materials was the Jolly Balance, invented by German physicist Philipp von Jolly in 1864 (Jolly 1864). Berman (1939) contributed a torsion microbalance capable of measuring minute mineral samples with an accuracy of 0.01mg or 1.0 x 10^{-5}g. Modern laboratory techniques commonly rely on pycnometer methods for specific gravity determination of soils and small particles. Hydrostatic methods are customary in the jewelry and gem industry, sometimes with elaborate and expensive set-ups using precision analytical balances (Read 2012, p.58-62). All of these methods are, unfortunately, confined to laboratory settings. Thus, specific gravity as an added tool for mineral identification in the field has always been relegated to approximation by simply hefting a sample and identifying the density as either high, intermediate or low (Klein and Philpotts 2012, p.53).

Major advances in weighing technology have not only lowered prices of balances drastically, but as with most electronics, the size of these instruments has been also significantly reduced. Precision weighing electronics can be inexpensively mass produced and have found their way into low cost consumer scales, a development that appears to have escaped the notice of geological scientists. The small size, built-in calibration modes, and portability point toward a good candidacy for fieldwork. The following study investigates the applicability of small, inexpensive, field porTable, electronic consumer balances for accurate quantitative determination of rock and mineral specific gravities in the field. In conjunction, a simplified approach was also developed to use said scales without any additional specialized materials, such as tripod stands or calibrated pycnometers, making the whole system very versatile and robust for a multitude of applications.

Method

In general, two types of weighing mechanisms are employed in electronic scales. Precision laboratory analytical balances use an ***electromagnetic balance system*** in which the counterweight on a fulcrum-beam is a measurable electromagnetic force. Less expensive electronic scales use a ***load cell*** which consists of an electrical resistance system mounted to an elastic aluminum body (Electromagnetic Type and Load Cell Type : SHIMADZU (Shimadzu Corporation) n.d.). For electromagnetic balances, internal electronics translate the amount of the electromagnetic counterbalance force into a digital, calibrated read-out. While these types of scales boast a very high precision and resolution, the internal fulcrum and associated electronics make them large and more sensitive to transport and changing environmental conditions.

Load cells on the other hand can be very small, allowing for balances the size of credit cards. As weight is placed on the scale, the load cell deforms, thus changing the internal electrical resistance. This in turn can be translated into an associated weight readout (Load Cell and Weigh Module Handbook - A Comprehensive Guide to Load Cell Theory, Construction and Installation 2010). Because the mechanism and electronics are very simple, these types of scales are fairly inexpensive. The inherent drawback has been a lower resolution and limited accuracy. However, in recent years small load-cell type porTable scales have been marketed with a capacity and resolution of 300g x 0.01g to 60g x 0.01g. Using these porTable balances while simplifying the density measurement approach should yield quantifiable, rapid, useful specific gravity data for rocks and minerals.

Specific gravity is a weight-to-volume ratio expressed in the metric system as g/cm^3 or kg/m^3, calculated according to $SG=V/W$.

The measurement of the weight of a specimen usually does not pose a problem. Obtaining exact volumes, however, can be challenging. One of the simplest procedures to accurately determine the volume of a specimen is based on the Single Pan Hydrostatic method (Read 2012, p.60-61) employing the Archimedes principle.

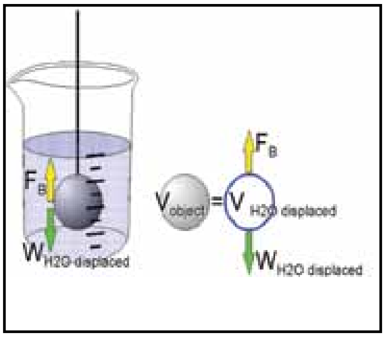


Figure 1- Archimedes' principle: The volume of a submersed object equals the volume of the amount of water displaced by the object. The weight of the displaced water is equal to the buoyant force acting on the object ($W_{H2O\ displaced} = F_B$). Therefore the force of the weight of the displaced water is added to the system of beaker, water, and suspended object which can be measured directly. Because the density of water is 1.0 g/cm³ @ 4°C, the $W_{H2O\ displaced}$ is equal to $V_{H2O\ displaced}$ which in turn is equal to V_{object}.

As illustrated in Figure 1, an object submersed in water will displace the same volume of water as the volume of the object, hence $V_{object} = V_{H2O\ displaced}$. The weight of the displaced water is equal to the buoyant force acting on the submerged object or $W_{H2O\ displaced} = F_B$. Using the concept of equal and opposite forces, $W_{H2O\ displaced}$ is added to the system of beaker, water, and the freely suspended and submersed object. Thus, if a scale is employed, F_B and therefore $W_{H2O\ displaced}$ can be measured directly. The density of water given as 1.0 g/cm³ (at 4°C) makes it possible to easily convert the weight of displaced water into the volume of the object according to $W_{H2O\ displaced} = V_{H2O\ displaced} = V_{object}$. Hence the direct reading of the displaced water force on the balance will yield the desired volume of the specimen needed in specific gravity calculations. Even though water densities are slightly lower than 1.0 g/cm³ at room temperature, the deviation is negligible in specific gravity measurements of gram sized samples and no correction is needed. The practical procedure for this approach is simple and straightforward.

Materials needed

The following materials are involved for the determination of specific gravity in the field:

1. PorTable load cell electronic scale with gram readout, tare function and a capacity to resolution of at least 100g x 0.01g
2. Calibration weight for the balance
3. A lightweight 125mL plastic specimen cup with lid
4. About 30 cm of fine string or yarn. Nylon monofilament preferred. For increased accuracy when measuring small specimen, use Nylon-12 type monofilament fiber (very difficult to obtain)
5. About 100mL of water
6. (Optional) Calculator or Nomograph (see Appendix) to quickly compute specific gravity from measurements

Procedure

Step 1: Balance is turned on and calibrated according to instructions. Since the electronic load cell will be influenced by temperature and vibrations, calibration is imperative when starting a measurement series, especially in field applications. It takes only a few seconds and most balances will have a user friendly autocalibrate function.

Step 2: Use a homogenous specimen and weigh in grams on balance. Record measurement as W_{air}.

Step 3: Tie slip knot into string or thread and attach specimen to string.

Figure 2 - Measurement of sample volume by freely suspending and submersing specimen in a water-filled and tared plastic container. Balance readout is equivalent to volume of object in cm³.

Step 4: Fill plastic container with water and place on scale. Use tare function to reset balance to zero.

Step 5: As shown in Figure 2, submerse specimen in container while holding the string. Make sure the sample is completely submersed and does not touch bottom or side of container. ***Caution***: Air bubbles may cling to the specimen and can falsify readings considerably if not removed, particularly when measuring smaller samples. To dislodge air bubbles, submerse specimen repeatedly until bubbles are alleviated. Record this reading of the submersed material as volume (V).

Step 6: Calculate specific gravity by W_{air}/V or use nomograph (see Appendix) to obtain results.

Note: Incredibly, the entire measurement process including set-up and calibration should take no longer than 2 minutes.

Experimental Set-Up

In order to test the validity of this rapid field specific gravity method, a sampling of four different inexpensive consumer load cell balances from "US Balance - Wholesale Digital scales manufacturing and distributing *(www.usbalance.com)*" was used as indicated in Table 1. An Ohaus Adventurer Pro AV264 precision analytical balance acted as reference standard for this test series. Identical measurement procedures were utilized for all five scales with the exception of averting calibration for the Ohaus AV264, since electromagnetic balances do not require frequent standardization.

Test specimens for specific gravity determination consisted of five varied quartz samples (2.65 g/cm³), four impure barite pieces with a measured SG of 4.17 g/cm³ and four topaz specimens from the same source with a specific gravity of 3.53 g/cm³. The selected sample size for testing was based on most likely scenarios expected in the field, ranging from about 22g and 8.3cm³ to roughly 1.5 g and 0.4 cm³ specimens. The four consumer load cell scales were calibrated and measurements were performed according to the procedure listed above. Specific gravity was then calculated according to measured W_{air} divided by obtained V.

Results and Discussion

In order to validate the application of this method, both precision and accuracy were calculated from the test series results for each individual scale. The averages of this assessment are listed in Table 1.





Model	US-AWE	US-Glacier	US-Prospector	US-Siggi	Ohaus AV264
Capacity/ Resolution	300g /0.01g	250g /0.01g	150g /0.01g	500g /0.1g	260g /0.0001g
Acceptable Tolerance Rating	±0.02g	±0.02g	±0.02g	±0.2g	±0.003g
Dimension	5”x 3”x 0.625”	4.3”x 3.3”x 0.8”	2.875”x 4”x 1”	2”x 3.5”x 0.5”	12”x 11.8”x 8.7”
Determined SG Precision	97.1%	98.3%	98.6%	90.0%	98.3%
Determined SG Accuracy	99.8%	99.9%	99.8%	96.4%	99.8%

Table 1 - Balances and their specifications used for rapid field SG testing, including experimentally determined results for average precision and accuracy of balances in measuring specific gravity.

Precision is defined as “repeatability” of measurements or “spread of results” (Accuracy, Error, Precision, and Uncertainty n.d.). It can be calculated as

$$PRECISION = \frac{High - Low}{Average}$$

where the difference of the highest to lowest value of a measurement series is divided by the average of the data in the same measurement series. Values were established for the three independent minerals tested as well as the overall mean of the precision percentages for each individual balance.

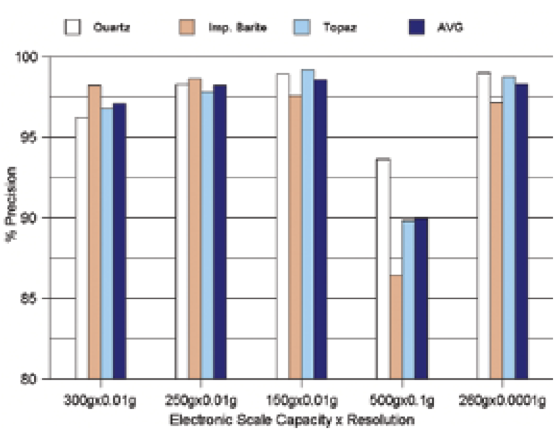


Figure 3 0 - Results of precision calculation for each scale assessed showing individual mineral test sets as well as overall precision averages per balance.

As illustrated in Figure 3, the precision of inexpensive consumer scales with a load cell system of 0.01g resolution are on par with the control provided by the Ohaus analytical balance in establishing specific gravities, ranging in overall performance from 94% to 97%. There appears to be a slight but negligible improvement in precision for load cell scales of lower capacities. However, the consumer scale with a resolution of 1/10th of a gram showed a significant loss in precision. While the precision assessment for quartz in the 0.1g readability balance is 93%, both topaz and impure barite are below the 90% mark. The smaller sizes of the test series for the last two minerals are not sufficiently resolved with the lower resolution of the US-Siggi consumer balance.

Accuracy is more difficult to analyze. It is defined as the closeness of a measured value to an accepted standard (Accuracy, Error, Precision, and Uncertainty n.d.). The inverse of accuracy is construed as accuracy error. Calculation of accuracy can be performed for each individual measurement if the accepted standard value is known. A standard value can be established through averaging multiple measurements across a variety of different instruments using the same testing material. The standardized density value for quartz is 2.65 g/cm^3. For the impure barite (4.17 g/cm^3) as well as the topaz mineral specimens (3.53 g/cm^3) a standard specific gravity value was established by averaging the measurements from the US-AWE, US-Glacier, US-Prospector, and the Ohaus AV264 balance. The measurements from the US-Siggi scale were not included because of the poor performance for specific gravity assessments due to low resolution.

Accuracy is calculated by dividing the measured value by the accepted or standard value as

$$\% \ ACCURACY = \frac{Measured}{Accepted} \times 100$$

The percent Accuracy Error is established by 100 - %Accuracy. Figure 4 summarizes the % Accuracy errors for individual measurements across the various scales tested.

With the exception of the lower resolution US-Siggi 500g x 0.1g balance, all higher resolution load cell balances perform similarly to the Ohaus 260g x 0.0001g analytical scale when assessing specific gravities of varied materials. Again, performance improves slightly with lower capacity load cell balances. All in all, accuracy errors for the 1/100th gram scales are very reasonable and stay below 2.5% for individual measurements with total average errors below 1%. The accuracy of these consumer scales is comparable to the laboratory analytical

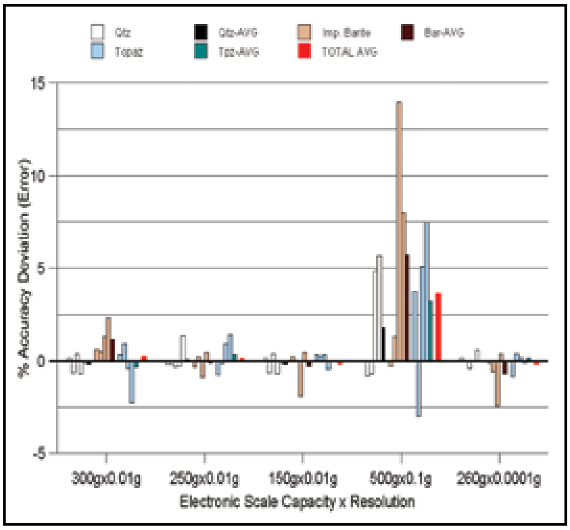


Figure 4 - Percent accuracy deviation (error) for each individual measurement series and total average per scale. Mineral specimens decrease in size and weight from left to right for each mineral test set and balance.

balance measurement in density assessments. The elevated deviation of the 3rd barite specimen from the standard, present within all scales but especially obvious in the Ohaus analytical balance reading, is most likely due to a higher impurity specimen within the rather heterogenous set of the barite test run.

Conclusions

The test shows conclusively that low cost consumer balances based on load cell electronics perform very adequately for specific gravity measurements as long as the resolution or readability is within 1/100th of a gram. Fortunately, a varied newer selection of load cell based consumer balances fills this requirement. It is noteworthy that both precision and accuracy are on par with analytical balances when establishing material densities through a single pan hydrostatic specimen submersion method. However, this accuracy is contingent on frequent calibration of such load cell scales as well as the removal of air bubbles in submersed specimens. Battery operation, small sizes and reasonably robust electronics make these scales porTable and a perfect companion for geologic field work. One of the smallest such consumer scales just recently released is the "American Weigh MB-100 Matchbox" balance with dimensions of a mere 1.4" x 2.9" x 0.5" and a capacity to resolution of 100g x 0.01g.

Most likely measurement errors are introduced when establishing the volume of samples, especially within small specimens. Possible discrepancies introduced through the yarn or thread employed to suspend the specimen are negligible and can be ignored. Those measuring very small samples on a routine basis may want to invest in a Nylon-12 monofilament thread, which has a density that approximates that of water at 1.02 g/cm^3, thus removing potential errors introduced by the added buoyancy of the string.

References

Accuracy, Error, Precision, and Uncertainty n.d., NDT Reference Information. NDT Resource Center. *http://www.ndt-ed.org/GeneralResources/ErrorAnalysis/UncertaintyTerms.htm,* accessed December 30, 2013.

Berman, Harry, 1939, A Torsion Microbalance for the Determination of Specific Gravities of Minerals. Am. Mineral 24: 434–440.

Doerfler, Ron, 2009, Creating Nomograms with the PyNomo Software. Document. Dead Reckonings - Lost Art in the Mathematical Sciences. *http://www.myreckonings.com/pynomo/CreatingNomogramsWithPynomo.pdf,* accessed December 30, 2013.

Electromagnetic Type and Load Cell Type: SHIMADZU (Shimadzu Corporation) N.d. *http://www.shimadzu.com/an/balance/support/hiroba/bean/bean04.html,* accessed December 28, 2013.

Jolly, Philipp von, 1864, Eine Federwage zu exacten Wägungen. In Sitzungsberichte der Königl. Bayerischen Akademie der Wissenschaften Pp. 162–166. urn:nbn:de:bsz:16-opus-127204, Munich: von F. Straub. *http://archiv.ub.uni-heidelberg.de/volltextserver/12720/,* accessed December 28, 2013.

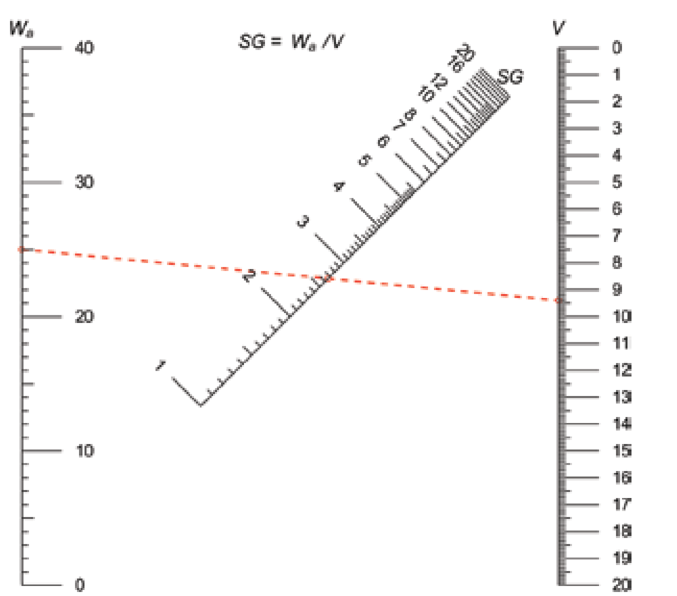
Klein, Cornelis, and Philpotts, Anthony, 2012, Earth Materials: Introduction to Mineralogy and Petrology. Cambridge University Press.

Load Cell and Weigh Module Handbook - A Comprehensive Guide to Load Cell Theory, Construction and Installation 2010. Rice Lake Weighing Systems. *http://www.ricelake.com/docs/prodinfo/Manuals/load-cells/lch_22054.pdf.*

Read, Peter, 2012, Gemmology. 2nd edition. Routledge.

Appendix

Specific Gravity Nomograph for rapid determination of rock/mineral density using the Hydrostatic One Pan Method and a consumer load balanced weighing scale with a resolution of 0.01g. Nomograph generated using Python programming language scripting in conjunction with PyNomo Version 1.1 Release 0.2.2 software (Doerfler 2009). *Example: Plot* W_{air} *of a specimen on the left vertical scale of the nomograph, here 25.00g. Mark V of specimen obtained through buoyancy measurements on the right vertical scale of the nomograph, example 9.40g. Connect both plots with a straight line. The intersection of this line with the diagonal scale gives the specific gravity, here 2.65 g/cm*^{3}.



The article was peer reviewed by Associate Editors Edward M. Baltzer, CPG-08861 and John L. Berry, CPG-04032.

Dr. Uwe Richard Kackstaetter, MEM-2437, a German native, received his M.S. in Geology from BYU, Provo and his Ph.D. in applied geology and mineralogy from the University of Würzburg, Germany. His professional expertise on two continents ranges from environmental testing of drinking water wells, groundwater flow modeling, site contaminant evaluations, as well as geologic and hydrologic field investigations. As an educator he has taught not only in college and secondary classrooms, he has also conducted numerous national and international geological field courses. Dr. Kackstaetter's current interests are in developing various practical approaches as advanced tools for the geosciences, such as automated percolation testers, new wavelength dependent night prospecting tools, improved processes of rock and mineral thin sectioning, and clay mineral analytical processing and computations. He currently works as Assistant Professor of Geology at Metropolitan State University of Denver where he teaches courses in Mineralogy and Optical Mineralogy, Hydrogeology, Applied Volcanology and Field Methods.

IN MEMORY

Walter Schmidt, CPG-06029, 63, of Tallahassee, Florida, passed away peacefully on March 29, 2014 in the arms of his loving family after a long and courageous battle with multiple myeloma and kidney failure. He was born in Philadelphia and moved to Melbourne, Florida to attend Florida Institute of Technology where he met his devoted wife of forty-one years, Cheryl. He earned his Bachelor's Degree at the University of South Florida and both a Master's and Ph.D. in Geology at Florida State University. He retired from the Geological Survey as the Director and State Geologist of Florida after 34 years of dedicated service. Walt was an incredible husband and father, a warm and caring person with an unassuming manner and a dry sense of humor. He enjoyed spending time with family camping and being at the beach. Walt was an avid sports fan, supporting the Florida State Seminoles.